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The Inequity of Biotechnological Impact

Less than 1% of the total population of the developing world is positively affected by biotechnological innovation. The global impact of biotechnology on agriculture is impeded by the disproportionate development and growth of economically important crops in the developed world. In over 2 decades, 526 genetically engineered events, or bioengineered (BE) traits, in 32 crops have been approved in 44 countries (ISAAA database, 2020). Of these 44 countries, 38 are high income, representing 73% of the developed world. Just six represent low-income countries, including four in Africa (ISAAA database, 2020). Although many countries import BE crops for feed, food, and processing, just over half of the 44 countries cultivate (ISAAA, 2017). Twenty years since their development, the acreage used for BE crops has increased from 1.7 million to 191.7 million hectares. This increase in growth is dominated by economically important crops such as cotton, maize, and soybean, which also account for 65% of new traits (Brookes and Barfoot, 2018). Minor or orphan staple crops, which are grown and consumed predominantly in Africa, Asia, and South America, lack the genomic resources and feasible approaches necessary for such scientific advances. Biotechnological advances have primarily focused on the challenges that farmers face: pests and pathogens. The majority of BE traits commercialized in economically important crops are involved in herbicide tolerance and insect and virus resistance (ISAAA database, 2020). However, scientific development does not always translate into commercialization or adoption. Academic collaborations with industry are often necessary to cover the average US$136 million cost and estimated 13 years from discovery and development to testing and approval of BE traits (McDougall, 2011). Although this cost is exorbitant for developing countries, the lack of innovation will cost low- and lower- to middle-income nations US$1.5 trillion in forgone economic benefit by 2050 (Giddings et al., 2016). Of the 20 existing commercialized crops, insect-resistant brinjal (eggplant) is the only minor crop currently represented. Although regional-specific varieties, such as drought-tolerant maize, herbicide-tolerant and insect-resistant sorghum, and virus-resistant bananas, are being developed (Blaustein, 2008), there is a clear discrepancy in funding and resources between major and minor crops. Thus, those with the greatest need benefit the least from science.

Population growth and the reliance on traditional and less efficient smallholder farming practices further exacerbate inequality and endanger the 1.4 billion children already facing food insecurity (Pardey et al., 2016). Biotechnological solutions to address agricultural problems could be developed; however, developing countries lack the funding mechanisms and support for vigorous research programs. In comparison, investment in research and development in developed countries rose from US$13.25 per person to US$17.73 in 30 years (Pardey et al., 2016), while in developing countries, investment decreased from US$1.73 per person to US$1.51 (Pardey et al., 2016). Currently, 9% of the world's population is undernourished, and deficiencies in iron, vitamin A, and zinc result in hundreds of thousands suffering from anemia, blindness, and stunted growth each year. Malnutrition is the largest contributor to disease in the world and is prevalent in the developing world, accounting for 45% of childhood mortality (FAO et al., 2020). Currently, 28.2% of children under 5 are stunted or wasted (Müller and Krawinkel, 2005), predominantly in Africa, Asia, and South America. However, practices to overcome nutrient deficiencies in other parts of the world, such as fortification during food processing or dietary supplementation in America and Europe, cannot be applied in many developing countries. With the advances in the molecular mechanisms of vitamin biosynthesis and metabolism, biotechnology could provide a solution to vitamin and mineral deficiencies (Jiang et al., 2020). Biofortification of orphan staple crops would provide vulnerable populations sustainable access to essential nutrients and has been successfully demonstrated in crops, including beta-carotene-enriched banana, canola, carrot, cauliflower, potato, rice, and tomato (Strobbe et al., 2018); iron-enriched grains and cassava; and protein-enriched sorghum (Hunt, 2003). However, approval and adoption of commercialized biofortified transgenic staples is hindered by the associated development and regulatory costs. For example, beta-carotene-enriched rice, developed in the late 1990s to combat vitamin A deficiency (VAD), took 2 decades to be approved and is yet to be adopted in regions suffering from VAD (ISAAA database, 2020). In the meantime, developing countries continue to suffer from endemic nutrient deficiencies, exacerbating the social and economic inequality that feeds into the cycle of poverty. The delayed adoption of biofortified staple crops in Africa, Asia, and South America is responsible for further loss of life that could have otherwise been prevented.

The global population is expected to reach 9.7 billion by 2050, with 97% of the population growth in food-insecure countries. Efforts to increase the yield of staple crops such as beans, cassava, maize, millet, rice, teff, sorghum, and wheat are essential (Giddings et al., 2016). Currently, Africa has achieved higher maize output through increased acreage for cultivation, rather than increased productivity per acre. Developing countries that are the least prepared for the consequences of climate change are disproportionately located in Africa. Rice imports are projected to rise by 57.8% by 2050 in sub-Saharan Africa. This dependence could be avoided by the development of BE staple crops and crop diversification (Mabhaudhi et al., 2019). Biotechnology has improved the lives of 65 million people, but this is just 1% of the total population of the developing world. Science could play a more significant role in ending world hunger, achieving food security, improving nutrition, and promoting sustainable agriculture, supporting the United

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Nations' Sustainable Development Goals, by 2030 (Sachs et al., 2020). However, to make scientific advancements have a wide impact, regulatory processes need to evolve, and infrastructures should be developed to generate and distribute new seed varieties. For the 2 billion people who are currently facing food insecurity and are unable to advocate for science, we need to ensure that the inequity of genetic engineering in the past does not repeat itself with gene editing of crops in the coming years. To ensure the application of gene-editing techniques to both economically important and staple crops, genomic resources need to be developed. Previously, the costs of sequencing crop genomes would have prevented gene editing in orphan staples. However, advances in sequencing technologies have led to more accurate and affordable genome sequencing. Complete, assembled, and well-annotated genomes are necessary for identifying potential target genes and potential off-targets, to ensure that unintended mutations are not introduced. The African Orphan Crops Consortium has successfully sequenced 8 of the 101 African orphan crop genomes it aims to sequence (Hendre et al., 2019). Applications of CRISPR that have been successfully demonstrated in crops include allele generation, biofortification, cryptic gene activation, *de novo* domestication, haploid induction, stress resilience, and delayed senescence (Pramanik et al., 2020). Biotechnological equality in agriculture requires open access to the latest scientific advancements, with journals, methods, and conferences, as well as open-source molecular and computational resources, which should be available to developing countries.

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